ATLAS Technical Coordination
Radiation Hardness Assurance Working Group
Coordinator: M. Dentan.

Report of the

Second meeting of the ATLAS Radiation Hardness Assurance Working Group

CERN, 593-R-10, 7 December 1999, 9:00-16:30.

The main purpose of this meeting was to prepare the revision 2 of the ATLAS policy on Radiation Tolerant Electronics.

Agenda:

I. Introduction: low dose rate effects on bipolar transistors:
- Facts; explanations of the mechanisms.

II. Proposed strategy for pre-selecting components and qualifying batches.
- Radiation constraint; radiation hardness required;
- Existing test methods;
- Procurement strategy.

III. Proposed standard test methods for ATLAS:
- Total ionising dose, displacement damages, single event effects.

IV. Radiation constraints in ATLAS detector and cavern.
- Available data; improvements required.

V. List of the components used in each ATLAS sub-system.
- Frame of the ATLAS electronics components data base.

VI. Irradiation facilities.
- Preliminary list.

VII. RHA-WG members.
- Official list.

Attendees:

Marie-Laure Andrieux (Grenoble / Atlas LARG), Francis Anghinolfi (CERN / Atlas SCT), Pierre Borgeaud (Saclay / Atlas LARG), Martin Dentan (CERN/ Atlas TC), Federico Faccio (CERN / COTS), Philippe Farthouat (CERN / Atlas TC), Philippe Grenier (Clermont / Atlas Tile), Bjorn Hallgren (CERN / Atlas DCS), Pierre Jarron (CERN / COTS), Werner Kubischta (CERN / Atlas cryogenics), Jose Pascual (Saclay / Atlas LARG), Vinnie Polychronakos (BNL / Moun CSC), Robert Richter (Munchen / Atlas Muons MDT), Giorgio Stefanini (CERN / CMS), Riccardo Vari (INFN Roma / Atlas Muons RPC).

I. INTRODUCTION: LOW DOSE RATE EFFECTS ON BIPOLAR TRANSISTORS

I.1. Facts:

P. Jarron reported the main results of a study of low dose rate effects on bipolar transistors made by Allan Johnston (Jet Propulsion Laboratory).

The degradation induced on bipolar transistors by Total Ionising Dose (TID) increases when the *dose rate* decreases. This phenomenon called Low Dose Rate Effect (LDRE) becomes significant with a dose rate of about 50 rad/s; it increases continuously when the dose rate decreases down to 0.001 rad/s or less. LDRE occurs even for very low TID (1 or 2 krads). LDRE depends on the technology (structure and thickness of the oxide surrounding the emitter), on the type of devices (LDRE are generally more severe on pnp than on npn transistors), on the biasing conditions (worst case: *biased* devices), on the design (lateral or vertical transistors). For the same device, LDRE varies strongly between manufacturers (factor 10 or more). No recovery is observed after irradiation on devices irradiated at low dose rate.

On elementary bipolar transistors, LDRE increases the degradation of the gain induced by TID. On bipolar circuits, LDRE increases the degradation of the gain of amplifiers, of the input bias currents, of the input offset voltages, etc.

I.2. Brief explanation of the mechanisms:

M. Dentan gave a brief explanation of the mechanisms responsible for low dose rate effects on CMOS and bipolar transistors. This explanation is summarised in appendix I.

II. PROPOSED STRATEGY FOR PRE-SELECTING COMPONENTS AND QUALIFYING BATCHES

II.1. Radiations constraints

Three types of radiation constraints will affect ATLAS electronics components:

- Particles producing *ionisation* in silicon oxide: photons, protons, pions, ions, (…).The unit to represent these particles is the total ionizing dose (TID) expressed in Gray.
- Particles producing *atomic displacements* in silicon: hadrons. The unit to represent these particles is the 1 MeV equivalent neutron fluence.
- Particles producing *Single Event Effects* (including SEU = single event upsets, SEL = single event latch-up, SEB = single event burn-out, SEGR = single event gate rupture). These particles can be incident particles, or particles resulting from interactions of incident particles with the material of the electronics components. The unit used to represent these particles is the linear energy transfer (LET). The units used to represent the sensitivity of a given device to SEE are the threshold LET (minimum LET required to produce a SEE) and the saturated cross section (surface of the sensitive nodes).

II.2. Radiation hardness required at test level:

Radiation levels have been simulated by Mike Shupe (University of Arizona) for the various regions of ATLAS where electronics systems will be located. Safety factors (SF) must be applied on these simulated radiation level to estimate the *radiation hardness required at test level* for the electronics components of the various electronics systems:

- SF1 = 4 to 6 represents the inaccuracy of the simulation (description of the system, ...);
- SF2 = 5 represents LDRE (when no experimental approach exists);
- SF3 = 2 to 4 represents the radiation tolerance variation from lot to lot and within lots.

II.3. Existing test methods:

Standard test methods have been developed by the US DOD and by the ESA to estimate the radiation hardness of electronics components. Table 1 summarises the main effects of the radiation constraints on electronics components and the test methods suitable to evaluate these effects.

Particles	**Basic effects**	**Main units**	**Sensitive devices**	**Main Effects**	**Test method**
Hadrons	Displacement damage	1 MeV eq. neutron / cm2 fluence	Bipolar	Δ Beta	MIL 883 - 1017.2
			Diodes	Δ I(V)	MIL 883 - 1017.2
			JFETs	Δ Vp	MIL 883 - 1017.2
Photons, Electrons, Charged Hadrons.	Oxide ionisation @ high dose rate	Dose (Gy) dose rate (Gy/s)	CMOS	Δ Vt, I leakage	ESA spec. 22900 MIL 883 - 1019.5
			Bipolar	Δ Beta, I leakage	ESA spec. 22900 MIL 883 - 1019.5
	Oxide ionisation @ low dose rate	Dose (Gy) dose rate (Gy/s)	CMOS	Δ Vt, I leakage	ESA spec. 22900 MIL 883 - 1019.5
			Bipolar	Δ Beta	JPL approach ?
Protons, Pions, Energetic Neutrons, Ions.	SEU	Flux, LET	Logic circuits	Errors	ESA spec. 25100
		//	Memories	upsets	ESA spec. 25100
	SEL	//	CMOS circuits	short circuit	ESA spec. 25100
	SEGR	//	CMOS	short circuit	?
	SEB	//	CMOS, bipolar	short circuit	?

Table 1.

⇨ Standard test methods derived from DOD or ESA test methods must be defined and applied for the selection and the procurement of the components required by each ATLAS sub-systems (see section III).

II.4. Procurement strategy:

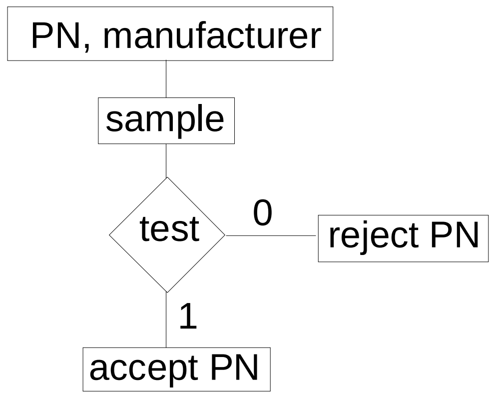
The participants to this RHA-WG meeting have defined a components procurement strategy in four steps. They agree to propose it to the ATLAS Executive Board, with the aim to use it as a standard for ATLAS.

<u>Step one:</u> listing of all the *components types* (part number PN, manufacturer) required to build the various electronics systems of ATLAS, with mention of the required quantities and the required radiation hardness (see details in appendix II).

<u>Step two</u> (fig. 1) : pre-selection of the *components types* (same part number, same manufacturer) which may withstand the required radiation hardness.

This pre-selection must be based on ATLAS standard test procedures (see section III). It must be made by sampling. The population sample must be large enough to enable statistical analysis (see standard test procedures).

Ideally, components must come from a known production line. However, in most of the cases, the customer only knows the name of the manufacturer, but he does not know if the components come from one or several production plant from the manufacturer around the world, or from another unknown manufacturer but with the stamp of the known manufacturer on the top of the package. The safety factor SF3 representing the variation of the radiation tolerance from lot to lot and within lots should cover these uncertainties.



<u>Figure 1.</u>

<u>Step three</u> (fig. 2) : qualification of the *lots of components* to be mounted in ATLAS electronics boards.

As for the pre-selection step, the qualification of lots of components must be based on ATLAS standard test procedures and must be made by sampling with a population sample large enough to enable statistical analysis.

Ideally, lots of components must come from a known production line and must have the same date and diffusion code. When this is not clearly stated, a *commercial lot of components* having the same part number and the same manufacturer name on their package can randomly contain components issued from several diffusion lots which could come from several production lines from several manufacturers. As for the pre-selection step, these uncertainties on the origin of the components must be covered by the safety factor SF3 representing the variation of the radiation tolerance from lot to lot and within lots.

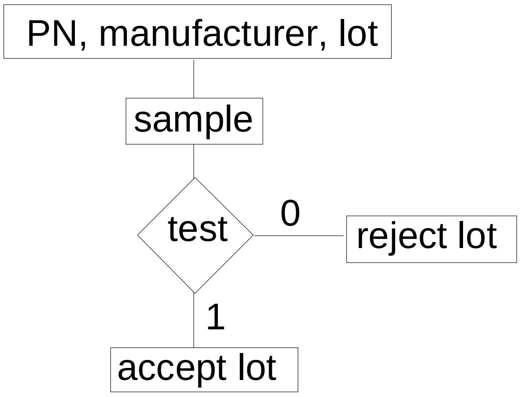


Figure 2.

Step four: Purchasing of the *lots of components.*

Ideally, step four must be made after step three. This requires good relations with the vendor, which must agree to "freeze" lots and to provide samples which the customer will test before deciding to purchase or to reject the frozen lots.

Most of the time, vendors cannot "freeze" lots and step 4 must be made before step 3. This induces the risk of purchasing bad commercial lots. To reduce this risk, *if no "test and purchase" agreement can be found with the vendor*, *the population sample in step 2 must be significantly higher than the minimum recommended* in the standard test procedures.

Result: these four steps lead to lots of *known good components*, ie components which are known to satisfy the required radiation hardness level.

III. PROPOSED STANDARD TEST METHODS FOR ATLAS

The participants to this RHA-WG meeting have examined in details three radiation test methods issued from DOD and ESA. They agree to propose them with several minor adaptations to the ATLAS executive board, with the aim to apply them as standard test methods, associated with the components procurement strategy presented in section II.4.

The original DOD and ESA test methods are:

- DOD MIL STD 883 test method 1017.2 (displacement damage test method);
- ESA SCC basic specification no 22900 (total ionising dose test method);
- ESA SCC basic specification no 25100 (SEU and latch-up test method).

They are available on the ATLAS Front-End Electronics web page (http://www.cern.ch/Atlas/GROUPS/FRONTEND/radhard.htm) :

- http://www.cern.ch/Atlas/GROUPS/FRONTEND/WWW/milstd~1.pdf
- http://www.cern.ch/Atlas/GROUPS/FRONTEND/WWW/22900.pdf
- http://www.cern.ch/Atlas/GROUPS/FRONTEND/WWW/25100.pdf

IV. <u>RADIATION CONSTRAINTS IN ATLAS DETECTOR AND CAVERN</u>

The ATLAS radiation environment has been simulated first by Paula Sala and Alfredo Ferrari (CERN), then by Mike Shupe (University of Arizona).

<u>Currently available data:</u>

The list of the available data on the ATLAS radiation environment is given in appendix III. These data include the TID required for total ionising dose tests and the 1 MeV equivalent neutron fluence required for displacement damage tests. However, *they don't include the total fluence of hadrons above 20 MeV required for SEE tests based on protons, nor the precise particle energy spectrums (maps with energy cuts) in the range 1 Mev – 20 MeV required for SEE tests based on neutrons.*

<u>Problems of accuracy :</u>

<u>Difference between two simulation codes</u>
The simulations made by Mike Shupe give more optimistic results (lower radiation levels) than those made by Paula Sala and Alfredo Ferrari. These two families of simulations have been made with two different codes. The difference between their results is large sometimes: a factor 5 on the neutron fluence, and a factor 2 on the total ionising dose. *These differences show that simulated radiation levels should in no way be used as exact values, and that they must be used very cautiously.*

<u>Possible errors</u>
Simulations made by Mike Shupe show *no photons* in the range 1 keV – 10 keV, whereas they show photons below 1 keV and beyond 10 keV. This probably results from an error.

<u>Obsolete results</u>
The data currently available result from simulation taking into account the main materials constituting ATLAS. However, when these simulations were performed, the final structure of *some of the sub-systems* was not decided. The final choice made on these sub-systems makes the simulation obsolete. New simulations could be necessary to avoid over-estimation of the radiation constraint in these sub-systems. This is particularly requested by the Tile Collaboration (see details in appendix IV).

<u>New simulations required :</u>

New simulations must be performed as soon as possible to provide ATLAS sub-systems with the missing data required for SEE tests and to correct the problems of accuracy mentioned above. Such simulations must be done by a person or a team willing to do this work and to improve it, according to ATLAS needs, during the next four years.

Vinnie Polychronakos (BNL) proposes to ask both Sue Willis (Northern Illinois University) and Mike shupe to perform these new simulations.

The new simulated radiation maps immediately required are:

Test	**Required map**
Displacement damage	- total fluence of 1 MeV equivalent neutrons, per year
Total Ionising Dose	- total ionising dose (Gy) , per year
Single Event Effects tested with protons	- total fluence of hadrons above 20 MeV, per year
Single Event Effects tested with neutrons	- fluence of neutron with energy cuts, per year; - fluence of electrons with energy cuts, per year; - fluence of total charged particles with energy cuts, per year; all these maps with the following energy cuts: • < 1 keV (1 map); • 1 keV – 10 keV (1 map); • 10 keV – 100 keV (1 map); • 100 keV – 1 MeV (1 map); • 1 MeV – 20 MeV by steps of 1 or 2 MeV (11 to 20 maps); • > 20 MeV (1 map).

V. LIST OF THE COMPONENTS USED IN EACH ATLAS SUB-SYSTEM

A preliminary frame of the ATLAS electronics components data base is given in appendix II. The final frame will be given in revision 2 of the ATLAS policy on radiation tolerant electronics.

VI. IRRADIATION FACILITIES

A preliminary list of some irradiation facilities is given in appendix V. A more complete list will be given in revision 2 of the ATLAS policy on radiation tolerant electronics.

VII. RHA-WG MEMBERS

The official representatives of all the ATLAS sub-systems have been designated by the coordinators of the sub-systems. The list of the members of the RHA-WG is given in appendix VI.

Appendix I

Mechanisms responsible for LDRE in CMOS and bipolar devices

LDRE occur in every device using silicon oxide, in particular MOS and bipolar transistors.

I. MOS transistors:

Ionising particles (photons, ions) induce electron-hole pairs in MOS gate oxide. Electrons have a high mobility and quickly leave the oxide. Holes have a low mobility and diffuse slowly; most of them are finally long-term trapped in the oxide near the edge of the oxide. These trapped holes produce an electrical field which induces a negative shift of the threshold voltage (Vt) of both NMOS and PMOS transistors. However, before leaving the oxide, some of the electrons are recombined with some of the holes. This recombination mechanism reduces the total quantity of holes which will be trapped in the oxide, and then reduces the negative Vt shift induced by the total absorbed dose. *The recombination rate depends on the dose rate. A high dose rate induces a high instantaneous density of electron-hole pairs which enhances the recombination rate. A low dose rate induces a low instantaneous density of electron-hole pairs (electrons quickly leave the oxide) which minimises the recombination rate.*

A second mechanism occurs in addition to the hole generation and trapping described below. Indeed, a fraction of the holes accumulated near the edge of the oxide will finally leave the oxide. When they leave the oxide at the interface between oxide and silicon, they produce defects in the silicon near this interface. These defects called interface states reduce the mobility of the carriers in the channel of MOS devices. They also trap electrical charges, according to the electrical bias applied on the gate. In PMOS devices, the gate is negatively biased and the charges trapped in interface states are positive (like the holes trapped in the gate oxide). These positive trapped charges produce an electrical field which induces a negative Vt shift, which then *increases* the negative Vt shift produced by the gate oxide trapped holes. In NMOS devices, the gate is positively biased and the charges trapped at the interface are negative (unlike the holes trapped in the gate oxide). These negative trapped charges produce an electrical field which induces a positive Vt shift, which then *decreases* the negative Vt shift produced by the holes trapped in the gate oxide. The global Vt shift of NMOS transistors depends on the ratio of the oxide charge density over the interface charge density. The magnitude of the Vt shifts induced by interface trapped charges depends on the density of the interface states, which depends on the density of holes accumulated in the gate oxide near the oxide-silicon interface, which is *controlled by the dose rate*.

In PMOS devices, the global Vt shift is always negative; it increases when the dose rate decreases.

In NMOS devices, the sign and the magnitude of the global Vt shift depends on the ratio of the oxide charge density over the interface charge density, which is controlled by the TID and by the dose rate.

Figure 3 illustrates the evolution of the NMOS Vt shift with the TID, in case of high dose rate and in case of low dose rate.

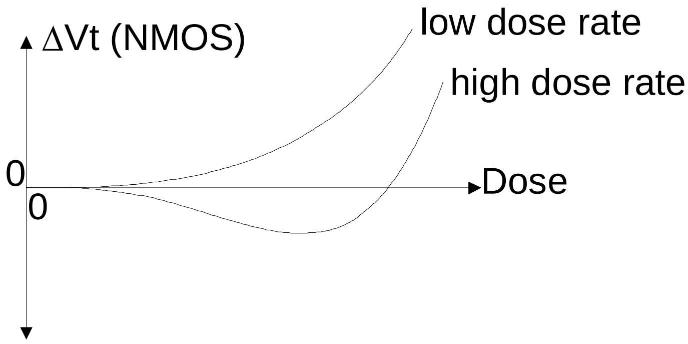


Figure 3: NMOS Vt shift versus dose, for low and high dose rates.

LDRE are important in the case of non rad-hard devices; they are small in the case of devices produced with a rad-hard technology.

II. Bipolar transistors:

As explained before, TID induces energy states in the oxides and in the silicon near the silicon-oxide interface. *The density of oxide states and of interface states increases when the dose rate decreases.*

Bipolar transistors involve oxide in their architecture. The emitter of lateral or vertical bipolar transistors is always surrounded by an oxide.

Before irradiation, the density of energy states at the interface between silicon and the oxide surrounding the emitter is very low, and the recombination of minority carriers (injected from the emitter into the base) on these interface states is negligible. The collector current Ic is the flux of carriers injected from the emitter into the base (these carriers diffuse through the base and reach the collector). The base current Ib is the flux of carriers injected from the base into the emitter. The gain of the bipolar is:

$$\beta_{pre\text{-}rad} = Ic/Ib.$$

After irradiation, the density of energy states at the interface between silicon and the oxide surrounding the emitter is high, it induces a significant recombination of minority carriers (injected from the emitter into the base) with majority carriers (coming from the base). This recombination current constitutes a parasitic base current (Ib') which adds to the regular base current Ib. The total base current (Ib+Ib') becomes significantly greater than the regular base current Ib. The gain of the bipolar transistor becomes:

$$\beta_{post\text{-}rad} = Ic/(Ib+Ib')$$

At high collector current, the interface states are saturated by the carriers issued from the emitter (which recombines with the majority carriers issued from the base). The parasitic base current reach a saturation value Ib'_{sat} which becomes more and more negligible (by comparison with Ib) when Ic (and Ib) increases. Consequently, at high collector current, the post-irradiation gain becomes close to the pre-irradiation gain. Inversely, at low collector current, there is no saturation of the interface states and thus the post-irradiation gain is strongly degraded by the parasitic recombination current Ib'.

TID induces interface state density which produces the gain decrease. As explained in the case of CMOS devices, *the interface state density induced by TID is higher at low dose rate than at high dose rate. Consequently, the degradation of the gain induced by TID is higher at low dose rate than at high dose rate.*

Figure 4 illustrates the evolution of the gain with the TID, in case of high dose rate and in case of low dose rate.

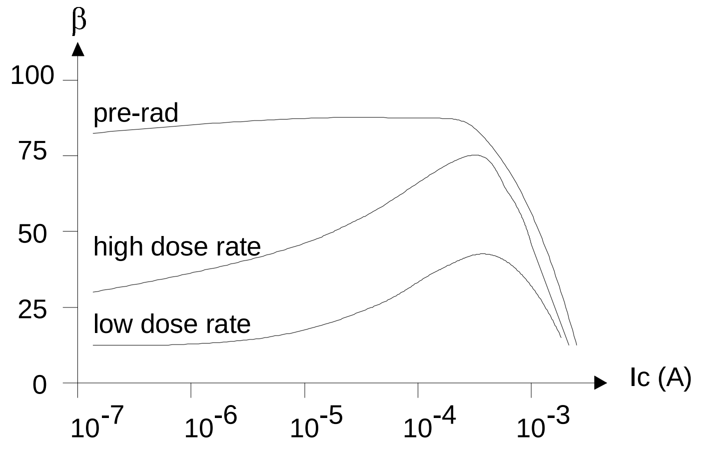


Figure 4: β(Ic) before irradiation and after irradiation at low and high dose rate.

Appendix II

Frame of the ATLAS electronics components data base (draft)

For each type of component, the following data are requested (when available):

General:

- Part number;
- Serial number;
- Manufacturer:
  - Name;
  - Address.
- Technology:
  - Type (CMOS, bipolar, BiCMOS, …);
  - Minimum geometry available;
  - Maximum number of interconnection layers available
  - Date of first commercial availability of the technology;
  - Date of end of life of the technology (if known).
- Packaging:
  - Type;
  - Number of pin;
  - Material.

Radiation hardness:

- Identification of the tested samples:
  - Production plant from where the tested samples come;
  - Date of manufacturing of the tested samples (date code);
  - Reference of the diffusion batch from which the tested samples come;
- Hardness to Total Ionising Dose:
  - Test method, radiation source, dose and dose rate used for the tests;
  - Total Ionising Dose producing the failure;
  - Failure mechanism(s).
- Hardness to displacement damages:
  - Test method, radiation source, fluence and flux used for the tests;
  - Total 1 MeV eq. neutron fluence producing failure;
  - Failure mechanism(s).
- Hardness to Single Event Effects:
  - Test method, radiation source, fluence and flux used for the tests;
  - For each type of SEE observed (SEU, SEL, SEB, SEGR): value of the LET threshold and of the saturation cross section.

Foreseen application:

- For each ATLAS sub-system:
  - Total number of parts required;
  - Radiation hardness required;
  - Contact person (address, phone, Email).

Appendix III

List of the available data on ATLAS radiation environment

(December 1999)

Data available in the ATLAS Policy on Radiation Tolerant Electronics version 1:

- Total neutron fluence in the best and worst ATLAS locations;
- 1 MeV equivalent neutron fluence in the best and worst ATLAS locations;
- 1 MeV equivalent neutron fluence map;
- Total ionising dose in the best and worst ATLAS locations;
- Total ionising dose map.

Maps available in the web site http://isnwww.in2p3.fr/atlas/andrieux/mshupe.html

- Total neutron flux;
- > 100 keV neutron flux;
- Total charged particles;
- Total deposited energy;
- Total ionisation dose;
- Photon above 30 keV;
- Photon above 300 keV;
- Total electron flux;
- Total muon flux;
- Star density.

Appendix IV

Material from the Tile Calorimeter which must be taken into account in new simulation of the radiation environment.

Figure 5 : radiation levels must be accurately calculated in the regions were the Tile Cal electronics will be located, ie on the top and on the bottom of the 70 mm thick aluminium drawers, inside the 175 mm square of the steel girders.

Figure 6 : the fingers (horizontally hachured region between the barrel and the extended barrel) will be full of cables and various electronics racks. The polyethylene blocks will contribute to reduce the neutron flux coming from the fingers into the drawers.

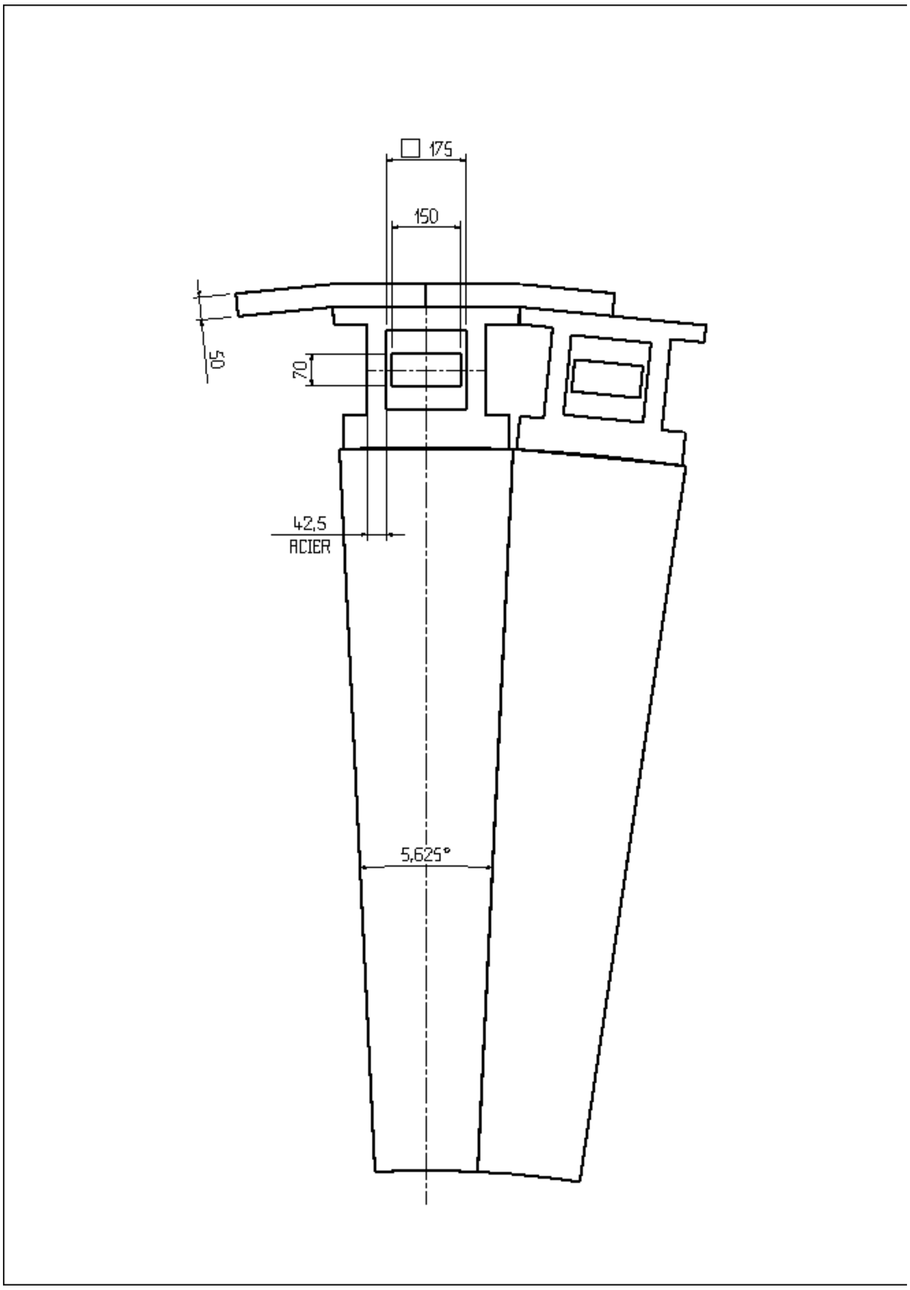


Figure 5

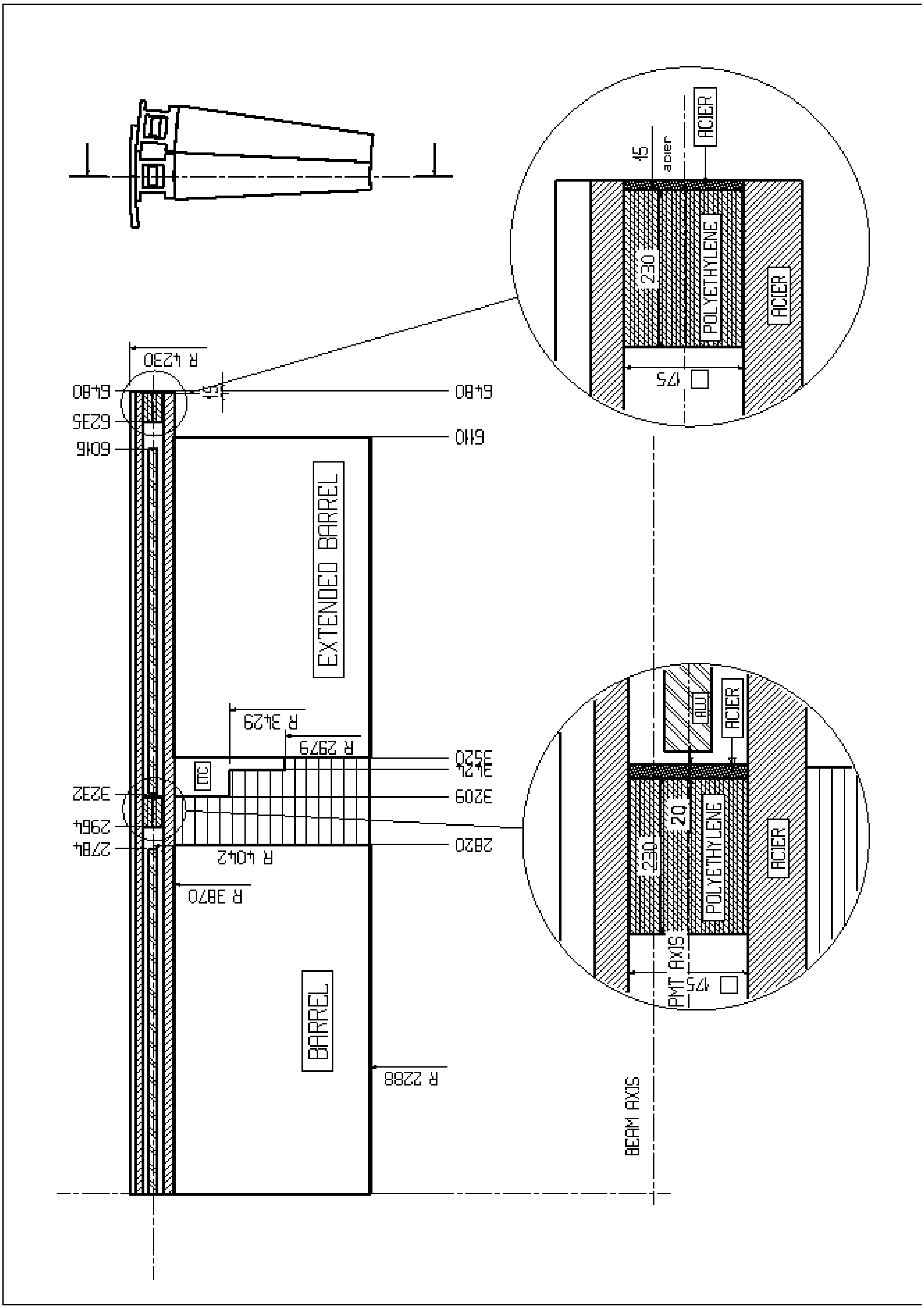

EXTENDED BARREL
BARREL
POLYETHYLENE
ACIER
acier
ALU
PMT AXIS
BEAM AXIS
R 4230
R 3429
R 2979
R 4042
R 3870
R 2288
6480
6235
6016
6110
3520
3424
3209
2820
3232
2964
2784
230
175
45
20

Figure 6

Appendix V

Some irradiation facilities (draft)

Gamma irradiations:

DELTA (DEIN) :
Contact person: Jean-Pierre Le Gac, Tel. +33 (0)1 69 08 67 45
Source : Co60 (340 mCi)
Volume: 100 dm3
Dose rates : 0.015 to 1.5 Gy/h

SIGMA (DEIN) :
Contact person: Jean-Pierre Le Gac, Tel. +33 (0)1 69 08 67 45
Source : Co60 (100 Ci)
Volume : 40 dm3
Dose rates : 23 to 260 Gy/h

IRMA (IPSN) :
Contact person: Jean-Pierre Le Gac, Tel. +33 (0)1 69 08 67 45
Source : Co60 (9510 Ci)
Volume : 24 m3
Dose rates : 25 to 8000 Gy/h

PAGURE (Cis Bio Industrie) :
Contact person: Technical: Alexandre Battung, Tel. +33 (0)1 69 85 71 17
Marketing: M. Duval, Tel. +33 (0)1 69 85 71 80
Source : Co60
Volume : room = 5 m length, 5m width, 3 m high
Dose rates : 20 kGy/h (inner region); 2 kGy/h (10 cm), 1 Gy/h (2.5 m).

GALAXIE (Cis-Bio Industrie):
Contact person: Technical: Alexandre Battung, Tel. +33 (0)1 69 85 71 17
Marketing: M. Duval, Tel. +33 (0)1 69 85 71 80
Source : Co60
Volume : 40 cm diameter, 50 cm high.
Dose rates : 2 kGy/h (mini), 5 Gy/h (maxi).

Neutron irradiations:

PROSPERO (DAM):
Location: Valduc (France)
Contact person: P. Zyromski, Tel. +33 (0)3 80 23 43 21
Source : Reactor
Volume: room = 10 m length, 8 m width, 6.5 m high
Mean energy: 0.75 MeV
Maximum flux: 0.8 E14 n.cm2/hour (1 MeV equivalent neutrons)
Very low gamma residual dose; accurate dosimetry.

See also M.L. Andrieux's web site: http://isnwww.in2p3.fr/atlas/andrieux/radfac.html#radfac

Appendix VI

RHA-WG members

Collaboration	Surname	First Name	Institute	Phone	Email
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Silicon Strip	Anghinolfi	Francis	CERN	+41 22 76 90 84	Francis.Anghinolfi@cern.ch
Silicon Strip	Kaplon	Jan	CERN	+41 22 767 81 21	Jan.Kaplon@cern.ch
TRT + ATLAS TC	Farthouat	Philippe	CERN	+41 22 767 62 21	Philippe.Farthouat@cern.ch
Larg calorimeter	Delataille	Christophe	LAL Orsay	+33 01 64 46 89 39	Taille@lal.in2p3.fr
Larg calorimeter	Borgeaud	Pierre	CEA Saclay	+33 01 69 08 61 65	borgeaud@hep.saclay.cea.fr
Larg calorimeter	Andrieux	Marie-Laure	ISN Grenoble	+33 04 76 28 41 28	andrieux@isn.in2p3.fr
Tile calorimeter	Grenier	Philippe	Clermont Fd	+33 04 73 40 77 93	grenier@clrhp04.in2p3.fr
Muon / CSC	O'Connor	Paul	BNL		poc@marlin.inst.bnl.gov
Muon / MDT	Richter	Robert	MPI Munchen	+49 89 32 354 358	Robert.Richter@cern.ch
Muon / TGC	Sasaki	Osamu	KEK	+81 298 64 54 36	sosamu@post.kek.jp
Muon / RPC	Vari	Riccardo	INFN Roma		Riccardo.vari@cern.ch
Magnet Control	Tyrvainen	Harri			Harri.Tyrvainen@cern.ch
DCS	Hallgren	Bjorn	CERN	+41 22 767 34 44	Bjorn.Inge.Hallgren@cern.ch
Crane	Inigo-Golfin	Joaquin			Joaquin.Inigo-Golfin@cern.ch
Cryogenics	Kubischta	Werner	CERN	+41 22 767 57 67	Werner.Kubischta@cern.ch
Radiation constraint	Shupe	Mike	Uni Arizona	+1 520 621 26 79	Shupe@uazhep.physics.arizona.edu
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